NAMI-1067
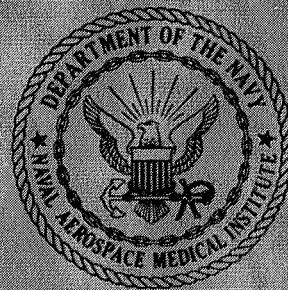
ISOTHERMAL METHOD FOR VOLUME DETERMINATION

Efrain Molina and James Knepton

JOINT REPORT

NAVAL AEROSPACE MEDICAL INSTITUTE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

April 1969

ISOTHERMAL METHOD FOR VOLUME DETERMINATION *

Efrain Molina and James Knepton

Bureau of Medicine and Surgery
MR005.01.01-0097B

NASA R-10-009-013

Approved by

Ashton Graybiel, M. D.
Head, Research Department

Released by

Captain J. W. Weaver, MC USN
Commanding Officer

15 April 1969

NAVAL AEROSPACE MEDICAL INSTITUTE
NAVAL AEROSPACE MEDICAL CENTER
PENSACOLA, FLORIDA 32512

THE PROBLEM

To find an accurate method for measuring weight of humans, animals, and objects in weightlessness. Present methods used to determine weight cannot be applied in weightlessness.

FINDINGS

An initial probe to determine the feasibility of measuring volume by an isothermal method and applying the method to computation of weight was successful. In a study of rhesus monkeys (Macaca mulatta), the method showed great promises for further development and subsequent use in space flight.

----

* The animals used in this study were handled in accordance with the "Principles of Laboratory Animal Care" established by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences, National Research Council.

INTRODUCTION

Presently there is no device of practical use that can "weigh" objects in weightlessness. To surmount this problem, an indirect volumetric weighing method based on gas principles and object density should be possible. The present report is an account of our first attempt to perfect such a method using a live anesthetized object, the rhesus monkey (Macaca mulatta). The results indicate that the method is promising and should be developed for space flight use.

MODEL

The method used here to measure the volume of an object is based on Boyle's Law that takes into account the relationship between changes of pressure and volume of a gas at constant temperature (isothermal process). The law is expressed as

$$P_1 V_1 = P_2 V_2 \tag{1}$$

where

P_1 = pressure of gas at condition 1

V_1 = volume of gas at condition 1

P_2 = pressure of gas at condition 2

V_2 = volume of gas at condition 2

The model shown in Figure 1 is composed of two vessels, Chambers 1 and 2, connected by a valve, VA1, which contain the volumes to be measured. Chamber 1 serves as a reservoir of given volume of air at a particular pressure above 1 atmosphere (atm) and Chamber 2 holds the object to be measured. Valve VA2 connects to a compressed air supply and valve VA3 serves as a relief valve for Chamber 2.

Initially VA1 is closed and VA2 is open until the air pressure inside Chamber 1 is at the desired value, P_{s1}. Valve VA3 is open until the inside air pressure equals atmospheric pressure, P_{at}, and then is closed, making sure no increase in air pressure occurs during its cut off. After VA2 is closed, valve VA1 is opened slowly to prevent abrupt temperature changes, and small transients are allowed to subside. At this point both Chambers 1 and 2 are at the same equalization pressure, P_E. Conditions before and after the opening of VA1 can be mathematically related by an equation

$$P_{s1} V_{c1} + P_{at} V_{c2} = P_E (V_{c1} + V_{c2}) \tag{2}$$
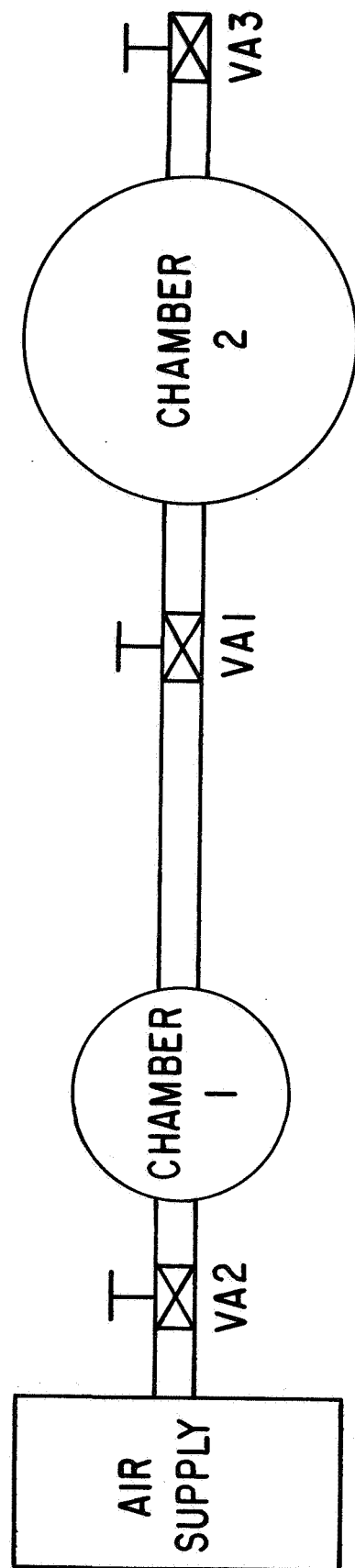
VA3

CHAMBER
2

VA1

CHAMBER
1

VA2

AIR
SUPPLY

2

Figure 1

Block Diagram Illustrating the Relative Arrangement of Components of
of an Isothermal Volumetric Device. See Text for Explanation
of Symbols and Operation

where

V_{c1} = volume of Chamber 1

V_{c2} = volume of Chamber 2

If an object whose volume is not known, V_x is put into Chamber 2, then conditions before and after opening VA1 are related in the following way:

$$P_{s1} V_{c1} + P_{at}(V_{c2} - V_x) = P_E (V_{c1} + V_{c2} - V_x) \tag{3}$$

Solving equation (3) for V_x, we obtain

$$V_x = \frac{V_{c1}(P_{s1} - P_E) - V_{c2}(P_E - P_{at})}{P_{at} - P_E} \tag{4a}$$

or

$$V_x = \frac{V_{c2}(P_E - P_{at}) - V_{c1}(P_{s1} - P_E)}{P_E - P_{at}} \tag{4b}$$

After simplication it becomes

$$V_x = V_{c2} - V_{c1} \cdot \frac{(P_{s1} - P_E)}{(P_E - P_{at})} \tag{4c}$$

Under the assumption that V_{c2} and V_{c1} are constants in the system, the accuracy in measuring V_x clearly depends on the accuracy of measuring P_{s1}, P_E, and P_{at}.

For small errors in measuring P_{s1}, P_E, and P_{at}, namely, ΔP_{s1}, ΔP_E, and ΔP_{at}, the error ΔV_x can be obtained from the following equation:

$$\Delta V_x = -\frac{V_{c1}}{(P_E - P_{at})^2} \left[(P_E - P_{at})\Delta P_{s1} + (P_{s1} - P_E)\Delta P_{at} - (P_{s1} - P_{at})\Delta P_E \right] \tag{5}$$

3

Equation (5) shows that, for a small value of ΔV_x, the following conditions are desired:

1) small value of V_{c_1}

2) a large value of $P_E - P_{at}$

Condition (2), above, simply states that the value of V_{c_2} should not be too much greater than the expected value of V_x; i.e., if $V_x = 1000$ in^3, V_{c_2} should be about 1500 in^3.

INSTRUMENTATION

Operation. Figure 2 is a picture of the volumetric device and Figure 3 shows a block diagram of the electronic instrumentation. With an object in Chamber 2, operation essentially consists of inserting air into Chamber 1 with VA1 closed and VA2 open, to a predetermined pressure, P_{s_1}, then closing VA2 and VA3. VA1 then is slowly opened and afterward a readout in pounds per square inch is made. Upon completion of a reading, VA1 is closed, VA3 opened, and another measurement made or the object is removed from Chamber 2.

Transducers. Two pressure transducers from Consolidated Electrodynamics Corporation, Model 5-413, are used. This model is a strain-gage, unbonded unit, having a range of 0 to 50 psia and requiring an excitation or supply voltage of approximately 5.0-Volt direct current. The supply voltage used is constant within ±5 mV. The output voltage from the unit is about 20 mV for a pressure equal to full scale value, i.e., 50 psia. The transducers are accurate within ±0.25 psia.

Both pressure transducers were calibrated to atmospheric pressure obtained from a barometer just prior to the experiment and maintained during all measurements.

D-C Amplifiers. The output voltage from each pressure transducer was amplified by a factor of 500 by means of an operational amplifier used in a noninverting mode. This is an analog device operational amplifier, Model 183 J, with a very small voltage offset, small drift, and high input impedance.

In order to filter out fluctuations which may be caused by the animal's breathing, a capacitor was placed in the feedback circuit of the operational amplifier. The amplifier has provision for zero suppression signals so that differential readings can be made; this feature was seldom used, however.

Output Readout. Each amplifier has its own meter circuit with provisions for the following:

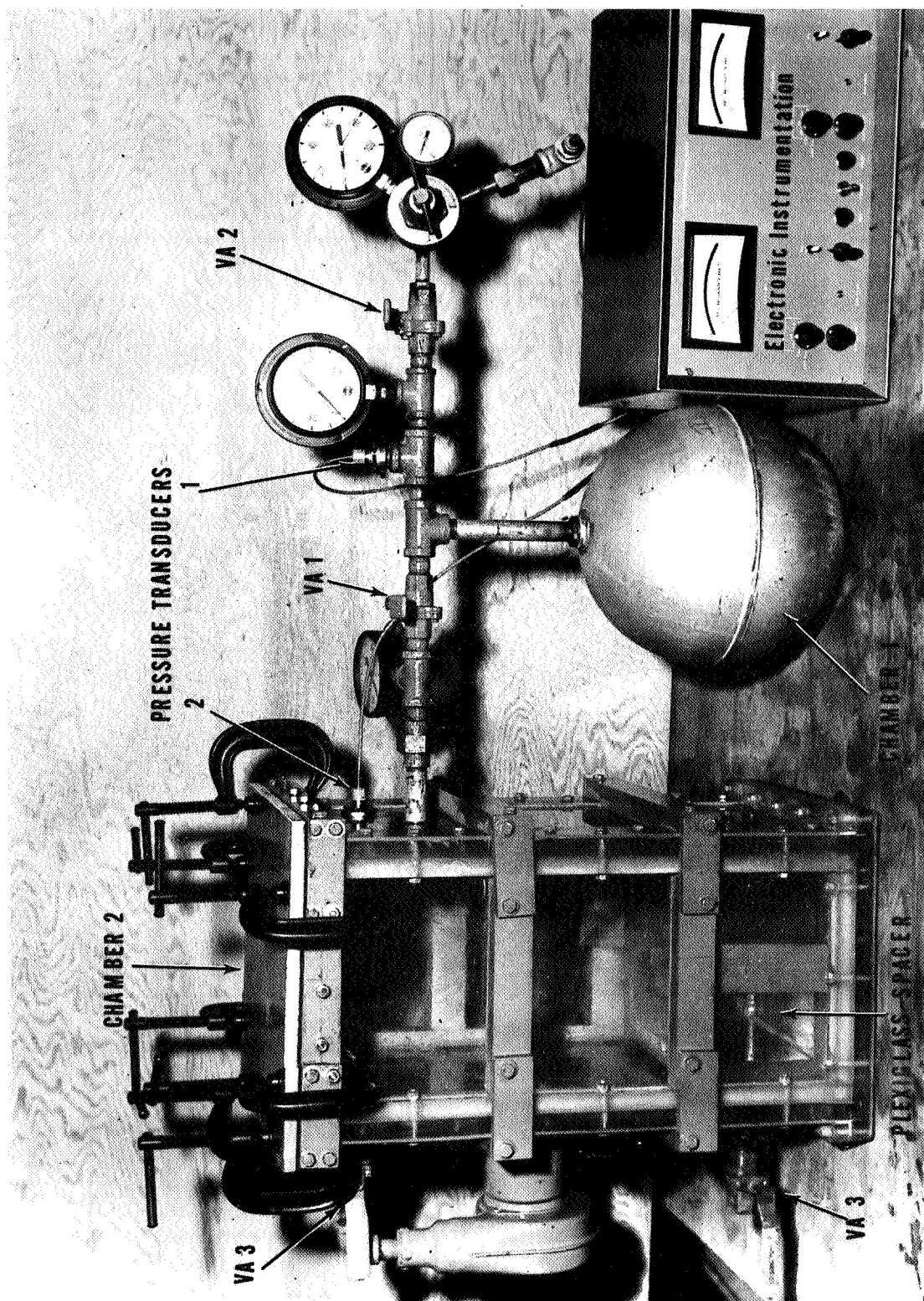a) Amplifier balance readout scale.

4

Figure 2

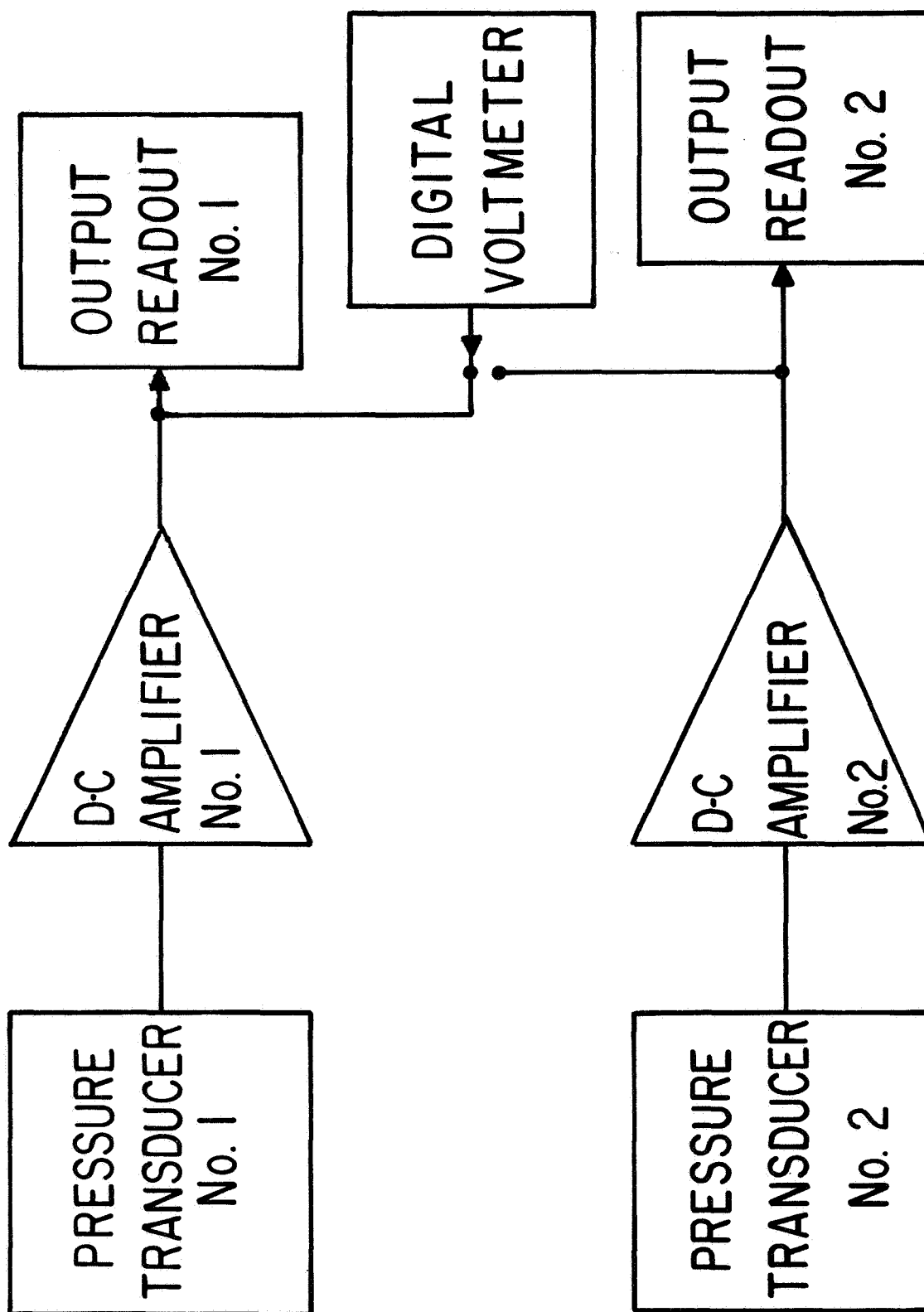Isothermal Volumetric Device Used for Rhesus Monkeys

Figure 3

Block Diagram of Electronic Instrumentation

b) A calibration scale to calibrate the pressure transducer (zero offset adjustment). The full scale indication is equivalent to ambient atmospheric pressure (usually 14.69 psia for this experiment).

c) Four output scales: 5,10,25, and 50 psia.

Since the accuracy of needle deflection-type meters is only 1 per cent, a Cimron digital voltmeter, Model 6653, was tried to improve the accuracy. This demonstrated that this latter type of meter should always be used.

TEST ANIMALS

Several rhesus monkeys (<u>Macaca</u> <u>mulatta</u>) of different scale weights and sex were subjected to volumetric measurements in Chamber 2. Prior to insertion in the Chamber the primates were sedated at the Vivarium with a drug, Inovar-Vet. For each measurement, a rhesus was subjected to equalization pressures of not more than 25 psia for about 5 minutes before returning to 1 atmosphere. A small ventilation fan provided air to the rhesus during nonpressurizing periods. Usually three measurements were done on each monkey. The veterinarian in attendance at the measuring sessions found no signs of aftereffects in the animals.

DISCUSSION

<u>Error</u>. A limited search of the literature revealed a method similar to the one reported herein but designed to measure the volume of liquids and using servosystems for obtaining the desired measurement (1). Another method used by the Northrop Systems Laboratories, but not fully described, showed an accuracy in the order of ±10 per cent (2).

Ours is truly an isothermal method, and careful steps were taken to make sure this condition was maintained. There were apparently three sources of error in our results: 1) accuracy of pressure transducer, 2) expansion of chamber walls due to increase in pressure, and 3) accuracy in obtaining measurements of the two chambers. The first source is treated in the preceding INSTRUMENTATION section. The other two kinds of errors were allowed for in calculating the animal's volume by taking the difference between the values of V_x of equation 4(c), with and without the animal. These errors were detected when it was discovered that equation 4(c) did not yield a zero value without the animal.

The overall inaccuracy of the system was found to be 0.5 pound.

<u>Temperature</u>. A mercury thermometer taped to the inside wall of Chamber 2 showed no indication of significant variations in temperature of the chamber during any of the measurements.

Weight. To convert volumetric data to weight, density of the animal (volume/ weight) has to be known. To give some idea of the way in which the isothermal volume method could be used to determine an animal's weight, it was assumed that the density of M. mulatta is 1.0. This results in 1000 cc/kg or 27.67 in^3/lb. In the two right hand columns of Table I it can be seen how nearly the weights from the macaques' volumes approximate their mechanical scale weights. Exact density measurements and scale weights are planned for more accurate comparison of the two measures.

Table I

Representative Pressure Readings, Calculated Volumes and Weights, and Comparable Scale Weights of Rhesus Monkeys *

Measurements	With Spacer#				Minus Spacer		
	ΔP_1	ΔP_2	$\Delta P_1/\Delta P_2$	V_x	V_{Rhesus}	Weight Density**=1.0	Weight Mechanical Scale
Rhesus 682, ♂							
1	17.725	11.875	1.493	1153.21	627.91	22.69	
2	17.715	11.915	1.487	1157.25	631.95	22.84	24.25
3	17.690	11.950	1.480	1161.96	636.66	23.00	
Rhesus 11G, ♀							
1	20.070	9.555	2.100	744.70	219.40	7.93	
2	19.925	9.470	2.104	742.00	216.70	7.83	6.83
3	19.600	9.390	2.126	727.20	201.90	7.30	
Rhesus 855, ♀							
1	19.325	10.015	1.9296	859.11	333.81	12.06	
2	19.265	10.070	1.913	870.55	345.25	12.48	12.00
3	19.250	10.065	1.913	871.22	345.92	12.50	

where

$$V_{c1} = 673$$

$$V_{c2} = 2158 \text{ \#}$$

$$\Delta P_1 = P_{s_1} - P_E$$

$$\Delta P_2 = P_E - P_{at}$$

$$V_x = V_{c_2} - V_{c_1} \frac{\Delta P_1}{\Delta P_2}$$

* All pressure (P) values are in pounds per square inch absolute; volume (V) in cubic inches; weight in pounds.

\# Hermetically sealed block of Plexiglas ($V_{ave.} = 525.3$) used to reduce V_{c_2} so that minimal error could be obtained for P_{s_1}, P_E, and P_{at}. See Figure 2.

** 27.67 in³/lb

‡ Includes errors of chamber measuring and chamber expansion at P>1 atm.

9

REFERENCES

1. Cohn, I. H., Gas laws provide new method of zero-g gaging. Space/
        Aeronautics, 45:102+, 1966.

2. Hesse, O. M., Orbiting experiment for study of extended weightlessness.
        NSL 67-302-2. Palos Verdes, Calif.: Northrop Systems Laboratories,
        1967.

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*	2a. REPORT SECURITY CLASSIFICATION
Naval Aerospace Medical Institute Pensacola, Florida 32512	Unclassified
	2b. GROUP N/A

3. REPORT TITLE

ISOTHERMAL METHOD FOR VOLUME DETERMINATION

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
N/A

5. AUTHOR(S) *(First name, middle initial, last name)*

Efrain Molina and James Knepton

6. REPORT DATE 15 April 1969	7a. TOTAL NO. OF PAGES 11	7b. NO. OF REFS 2
8a. CONTRACT OR GRANT NO. NASA R-10-009-013 b. PROJECT NO. BuMed MR005.01.01-0097B c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NAMI-1067 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* 1	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

An initial feasibility probe of an isothermal volume measurement method for application to weight measuring was found to be promising. Rhesus monkeys (Macaca mulatta) were used as test animals.

DD FORM 1473 (PAGE 1)
1 NOV 65

S/N 0101-807-6801

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Volumetric method						
Weightlessness						
Macaca mulatta						